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MODEL-BASED ANALYSIS OF ASSOCIATIVE RECOGNITION, TEMPORAL CONTEXT AND RETRIEVAL DYNAMICS

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14. ABSTRACT

Report developed under USAF Grant/Cooperative Agreement for research interests of the Air Force Office of Scientific Research, AFOSR-BAA-2010-1. Perception and memory are both pivotal in various forms of skilled human performance. This project's goal was produce a quantitative account of the interactions between these two forces, examining ways in which they either enhance or limit one another. The immediate twin aims of the project focussed on the computations by which diverse sources of information are integrated in order to support memory. Aim One examined the associative mechanisms and strategies that integrate auditory and visual information into a form that supports associative recall; Aim Two examined the integration of information defined along the disparate dimensions of temporal context and item attribute.

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Work performed under AFOSR contract FFA9550-10-1-0420: Model-based Analysis of Associative Recognition. Temporal Context and Retrieval

Robert Sekuler, PI

December 12, 2013

The following sections describe the principal results of projects supported by this contract.

1 Memory and incidental learning for visual frozen noise sequences

Published in *Vision Research* 2013, in press
Contributors: Jason M. Gold, Avigael Aizenman, Stephanie Bond & Robert Sekuler

1.1 Project Summary

Five experiments explored short-term memory and incidental learning for random visual spatio-temporal sequences. In each experiment, human observers saw samples of 8 Hz temporally-modulated 1D or 2D contrast noise sequences whose members were either uncorrelated across an entire one-second long stimulus sequence, or comprised two sequences of "frozen noise" that repeated identically between a stimulus' first and second 500 ms halves (Repeated noise). Figure 1 shows the three types of stimuli in schematic fashion. Presented with randomly intermixed stimuli of both types, observers judged whether each sequence repeated or not. Additionally, a particular exemplar of Repeated Noise (a frozen or Fixed Repeated noise) was interspersed multiple times within a block of trials.

As previously shown with auditory frozen noise stimuli (Agus *et al.*, 2010) recognition performance (d') increased with successive presentations of a Fixed Repeated stimulus, and exceeded performance with regular Repeated Noise. However, unlike the case with auditory stimuli, learning of random visual stimuli was slow and gradual, rather than fast and abrupt. Reverse correlation analysis revealed that contrasts occupying particular temporal positions within a sequence had disproportionately heavy weight in observers' judgments. An analysis of performance changes with repeated, occasional presentation of the same stimulus exemplar demonstrated learning, despite the fact that such learning was utterly incidental to the subjects' actual task. A subsequent experiment suggested that this result arose from observers'

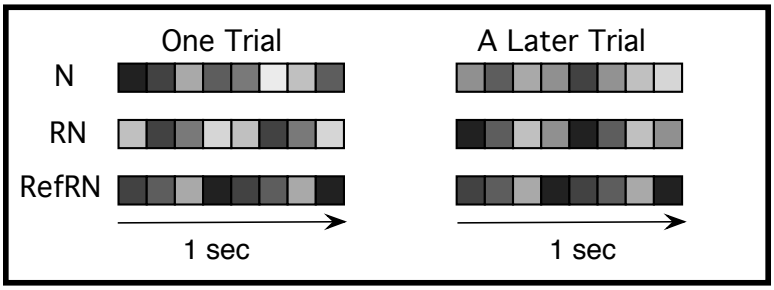

Figure 1: Schematic of stimulus sequences used in Project 1. RefRN = Fixed Repeated noise sequence; RN = Repeated Noise sequence.

uncertainty about the temporal mid-point of the noise sequences. Additionally, discrimination performance fell dramatically when a sequence of contrast values was repeated, but in reverse ("mirror image") order. This very poor performance with temporal mirror images differs strikingly from the exquisite sensitivity that vision shows for spatial mirror images.

2 Multisensory integration in short-term memory

Not yet published. Manuscript is in draft form.
Contributors: Avigael Aizenman, Jason M. Gold & Robert Sekuler

2.1 Project Summary

This effort extends the approach developed in Project 1. Goals of this Project were to (i) replicate Project 1's basic findings on visual memory, (ii) assay for analogous effects in the auditory domain, (iii) examine effects of presenting concurrent correlated visual and auditory sequences, and (iv) examine the impact of music training's on subjects' ability to process rapidly-presented stimulus sequences. It is known that music training enhances multiple aspects of hearing, including ability to track the temporal profile of complex sounds, such as speech. To determine whether such training also affected visual processing and responses to correlated audio and visual signals, we assessed short-term memory for rapidly presented sequences of quasi-random auditory, visual or combined auditory-visual.

A monotonic correlation between luminance and pitch elements comprising a concurrent auditory-visual sequence not only sharpened perception, but produced an substantial improvement in short-term memory for the correlated inputs. Significantly, as Figure 2 shows, modest amounts of training to play an instrument enhances short-term memory not only for auditory sequences, but for visual and audio-visual sequences as well. This raises the intriguing question of whether music training might have a broad beneficial impact on ability to process and recognize sequences more generally.

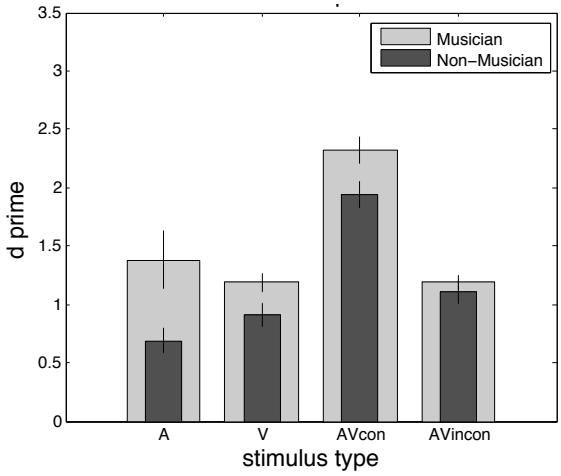

Figure 2: Principal results of Project 2. Performance, expressed in the metric of d', is shown separately for subjects who had musical training and subjects who did not. A = sequences comprising items of varying pitch; V = sequences comprising items of varying luminance; AVcon = sequences in which concurrent items were monotonically related in luminance and pitch; AVincon = sequences in which concurrent auditory and visual items were uncorrelated in luminance and pitch.

3 Paying attention to attention in recognition memory: Insights from models and electrophysiology

Published in *Psychological Science*, October 25, 2013
Contributors: Chad Dube, Lisa Payne, Robert Sekuler & Caren M. Rotello

3.1 Project Summary

Reliance on remembered facts or events requires memory for their sources, that is, the contexts in which those facts or events were embedded. Understanding of source retrieval has been stymied by the fact that uncontrolled fluctuations of attention during encoding can cloud important distinctions between competing theoretical accounts. To clarify the issue, we combined electrophysiology (high-density EEG recordings) with computational modeling of behavioral results. We manipulated subjects' attention to an auditory attribute, whether the source of individual study words was a male or female speaker. Posterior alpha band (8-14 Hz) power in subjects' EEG increased after a cue to ignore the gender of the person who was about to speak. With control of subjects' attention validated by the pattern of EEG signals, computational modeling showed unequivocally that memory for source (male or female speaker) reflects a continuous,

signal detection process rather than a threshold recollection process. Unfortunately, we were not able to test enough subjects to support an examination of individual differences in ability to filter out extraneous sources of information. Clearly, that would be a useful follow up to this project.

4 The importance of ignoring: Alpha oscillations protect selective processing

Published in *Current Directions in Psychological Science,* in press.
Contributors: Lisa Payne & Robert Sekuler

4.1 Project Summary

Selective attention is often thought to entail an *enhancement* of some task-relevant stimulus or attribute. We discuss a somewhat different perspective, namely that ignoring irrelevant, distracting information plays a complementary role in information processing. Cortical oscillations within the alpha (8-14 Hz) frequency band can serve as a marker of sensory suppression. This suppression is linked to selective attention for visual, auditory, somatic, and verbal stimuli. Inhibiting irrelevant processing allows us to make more accurate and timely responses. It also helps protect material that we hold in short-term memory from being disrupted. Furthermore, this selective process keeps irrelevant information from distorting the precision of memories. At best, human memory is only as good as the perceptual representations on which it depends, and on the ability to maintain those representations in useful form. Modulation of cortical alpha oscillations can be exploited as an active, purposeful mechanism to help people pay attention and remember the things that matter.

5 Similarity-based distortion of short-term visual memory is perceptual

Published in *Vision Research*, 2013, in press
Contributors: Chad Dubé, Feng Zhou, Michael J. Kahana & Robert Sekuler

5.1 Project Summary

A task-irrelevant stimulus can distort recall from visual short-term memory. Specifically, the recalled stimulus can take on some of the appearance of an accompanying task-irrelevant stimulus (Huang & Sekuler, 2010). However, the locus of this robust effect is unknown as it is unclear whether distortion is generated early, during perceptual encoding of target stimuli, or later, during some post-perceptual representation in memory. To select between these two accounts, we

manipulated subjects' attention to target and non-target stimuli whose similarity relationships were varied parametrically. On each trial, subjects were shown one or two Gabor patches, followed by a probe; their task was to indicate whether the probe matched one of the study items. A brief cue told subjects which Gabor, first or second, would serve as that trial's target item. Critically, this cue appeared either before, between, or after the study items.

False alarm rates varied substantially with the probe's similarity to a trial's task-irrelevant study item, confirming that the task-irrelevant item impacted visual encoding of the target. A drift-diffusion model (Ratcliff, 1978) was applied simultaneously to subjects' choice probabilities and reaction times. Model fits revealed that both lure similarity and cue timing affect the model's mean drift rate parameter, which represents the accumulation of sensory information. This suggests that selective attention in the pre-cue condition operated on the encoding of target stimuli, consistent with a perceptual account of the distortion's origin. The publication discusses the implications of these results for theories of visual short-term memory.

6 Aging and audio-visual and multi-cue integration in motion

Published in *Frontiers in Psychology*, May 23, 2013
Contributors: Eugenie Roudaia, Allison B. Sekuler, Patrick J. Bennett & Robert Sekuler

6.1 Project Summary

The perception of naturalistic events relies on the ability to integrate information from multiple sensory systems, an ability that may change with healthy aging. When two objects move toward and then past one another, their trajectories are perceptually ambiguous: the objects may seem to stream past one another or bounce off one another. Previous research showed that auditory or visual events that occur at the time of disks' coincidence could bias the percept toward bouncing or streaming. We exploited this malleable percept to assay age-related changes in the integration of multiple inter- and intra-modal cues. The disks' relative luminances were manipulated to produce stimuli strongly favoring either bouncing or streaming, or to produce ambiguous motion (equal luminances). A sharp sound coincident with the disks' overlap increased both groups' perception of bouncing, but did so significantly less for older subjects. An occluder's impact on motion perception varied with its duration: a long duration occluder promoted streaming in both groups; a brief occluder promoted bouncing in younger subjects, but not older ones. Control experiments demonstrated that the observed differences between younger and older subjects resulted from neither age-related changes in retinal illuminance nor age-related changes in hearing, pointing to weakened inter- and intra-modal integration with aging. These changes could contribute to previously demonstrated age-related perceptual and memory deficits.

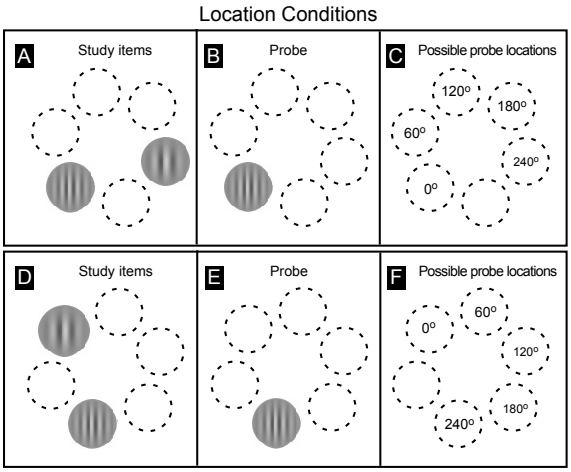

Figure 3: Schematic of conditions used in Project 8. Stimuli were Gabors whose spatial frequency was varied; two Gabor study items were briefly presented on each trial. These were followed by a test Gabor whose spatial frequency, on half the trials, matched that of one of the study items. Subjects were instructed to ignore location and judge whether there was a match solely on spatial frequency.

7 Age-Related Changes in Expectation-Based Modulation of Motion Detectability

Published in *PLoS One*, August 9, 2013
Contributors: Theodore P. Zanto, Robert Sekuler, Chad Dubé & Adam Gazzaley

7.1 Project Summary

Expecting motion in some particular direction biases sensitivity to that direction, which speeds detection of motion. However, the neural processes underlying this effect remain underexplored, especially in the context of normal aging. To address this, we examined younger and older adults' performance in a motion detection task. In separate conditions, the probability was either 50% or 100% that a field of dots would move coherently in the direction a participant expected (either vertically or horizontally). Expectation and aging effects were assessed via response times (RT) to detect motion and electroencephalography (EEG). In both age groups, RTs were fastest when motion was similar to the expected direction of motion. RT tuning curves exhibited a characteristic U-shape such that detection time increased with an increasing deviation from the participant's expected direction. Strikingly, EEG results showed an analogous, hyperbolic curve for $N1$ amplitude, reflecting neural biasing. Though the form of behavioral

and EEG curves did not vary with age, older adults displayed a clear decline in the speed of detection and a corresponding reduction in EEG $N1$ amplitude when horizontal (but not vertical) motion was expected. Our results suggest that expectation-based detection ability varies with age and, for older adults, also with axis of motion.

8 What is where's influence on short-term visual recognition?

Not yet published. Manuscript is in draft form.
Contributors: Jie Huang, Chad Dubé & Robert Sekuler

8.1 Project Summary

Recognition of an object is undermined if that object appears in an unusual spatial context. Thus, an object's "where" affects recognition of its "what." This effect can persist even when location should be irrelevant. To examine the linkage between memory for "what" and "where," we isolated each dimension's influence on recognition, using Gabor stimuli as study items and probes. We varied (i) a probe's featural similarity to the study items, and, at the same time (ii) the similarity of the probe's spatial location to the spatial locations of the study items. These manipulations are illustrated in Figure 3.

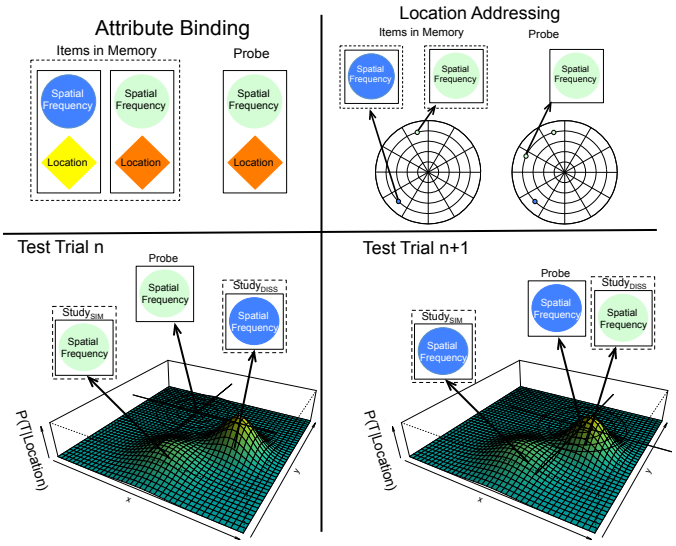

Figure 4: Diagram illustrating possible models by which the nominally task-irrelevant stimulus attribute (location) might influence subjects' performance in Project 8. P(T|Location) represents the probability that the target (test Gabor whose spatial frequency matches that of one of the study Gabors) appears in a given location.

A mismatch between the location of the probe and its most similar study item exerted a graded influence that spread over considerable distance. In turn, this graded influence strongly modulated the impact of the featural similarity between probe and study items. Application of the Drift Diffusion Model (DDM) to reaction times and recognition responses supported this interpretation. The DDM analysis revealed multiplicative effects of context and similarity on the rate of evidence accumulation: accumulation rates varied with featural similarity, an effect that was strongest for probes tested at locations farther from the best-matching study items. Finally, our results demonstrate that short-term visual recognition entails a global matching process of the sort proposed in Sekuler & Kahana (2007).